

APPLICATION  
FOR  
UNITED STATES LETTERS PATENT

TITLE: SENSITIVE POLARIZATION MONITORING AND  
CONTROLLING

APPLICANT: X. STEVE YAO

CERTIFICATE OF MAILING BY EXPRESS MAIL

Express Mail Label No. EV 399311335 US

1/13/2004  
Date of Deposit

**SENSITIVE POLARIZATION MONITORING AND CONTROLLING**

[0001] This application claims the benefit of U.S.  
Provisional Application No. 60/440,007 entitled "Sensitive  
Polarization Monitoring and Controlling" and filed on  
5 January 13, 2003, the entire disclosure of which is  
incorporated herein by reference as part of this  
application.

**Background**

10 [0002] Optical polarization is an important parameter in  
many optical devices and systems. A change in optical  
polarization of light may modify behavior of light or  
operation of optical devices and systems. Hence, it is  
desirable to monitor optical polarization of light in  
15 various applications. For one example, various optical  
polarization stabilizers may use an optical polarizer for  
monitoring the polarization.

**Summary**

[0003] This application includes techniques, devices and  
20 systems that use a two polarization elements in a  
polarization monitoring device to monitor polarization  
state of light.

[0004] In one implementation, a method for monitoring  
polarization of light includes the following steps. A

first partial polarization beam splitter is used to split  
by reflection a fraction of light in one of first and  
second mutually orthogonal polarization directions from an  
input beam to produce a first monitor beam. A second  
5 partial polarization beam splitter is used to split by  
reflection a fraction of the light in the one of the first  
and second mutually orthogonal polarization directions from  
the input beam to produce a second monitor beam. The first  
and second partial polarization beam splitters are oriented  
10 to have their polarization axes to be 90 degrees with each  
other. The first and the second monitor beams are then  
converted into first, and second detector signals,  
respectively. A difference between the first and the  
second detector signals are used to indicate an amount and  
15 a direction of a deviation in a polarization of the light  
from a known direction.

[0005] This and other implementations and variations are  
described in greater detail with reference to the drawings,  
the detailed description, and the claims.

**Brief description of the drawings**

[0006] FIG. 1 shows a transfer curve of a polarizer as a function of the polarizer angle.

5 [0007] FIG. 2 illustrates one exemplary implementation of a three-element polarization monitoring device.

[0008] FIG. 3 shows the variation of output signals V1, V2, and V3 from three PBS elements in FIG. 2 as a function of the input polarization angle when V3 reaches maximum, V1  
10 = V2 so that  $(V1-V2)=0$ .

[0009] FIG. 4 shows an exemplary implementation of the polarization control system based on the polarization monitoring device in FIG. 2.

15

**Detailed Description**

[0010] This application is in part based on the recognition that a polarizer when used a polarization monitoring device may not be sufficiently sensitive to variations in polarization when the polarizer is operated at angular locations A, B, or C in a transfer curve of the polarizer as a function of the polarizer angle. This is illustrated in FIG. 1. If the polarizer is set at the angle A (maximum transmission) or B (minimum transmission) in monitoring the polarization, the transmission power of the polarizer is least sensitive to a change in the polarization since the slope at A and B is zero. In addition, at these two operating angles A and B, the power change in the transmission of the polarizer does not directly indicate the direction of the polarization variation from the direction of the polarizer.

[0011] On the other hand, the transmission power of the polarizer would have a sensitive response to a change in the polarization angle when the polarizer is set to operate at the angle C at the waist of the transmission peak. However, the transmission loss in this operation mode is 3dB and the power fluctuation in the input light, such as the power variation in the light source, may directly

affect the accuracy of the polarization monitoring and thus the accuracy of the polarization control.

[0012] In addition, the operation at the point C presents another technical issue: the polarization under  
5 monitoring may not be unique for the same transmission output from the polarizer. For example, at the point C, two linear polarization states orientated at  $\pm 45$  degrees with respect to the passing axis of the polarizer and two circularly polarized lights (right and left hand) all have  
10 50% of the peak power in the transmission power.

[0013] FIG. 2 illustrates one exemplary implementation of a three-element polarization monitoring device 200 of this application. The device 200 includes 3 partial polarization beam splitters (PBS) 210, 220, and 230 that  
15 are disposed in the optical path of an input light beam 201. The partial PBSs 210, 220, and 230 are configured to partially reflect only one polarization of the two orthogonal polarizations, for example, "S" polarization, and do not reflect the other orthogonal "p" polarization.

20 The orientations of the polarization directions P1, P2, and P3 of the partial PBSs 210, 220, and 230 are also illustrated in FIG. 2. The 1<sup>st</sup> and 2<sup>nd</sup> partial polarization beam splitters 210 and 220 are oriented at  $90^\circ$  from each other and they are also oriented  $\pm 45^\circ$  from the 3<sup>rd</sup> partial

PBS 230. Three optical detectors 214, 224, and 234 are respectively positioned to receive reflected beams 212, 222, and 232 from the PBSs 210, 220, and 230, respectively, to produce detector output signals 216 ( $V_1$ ), 226 ( $V_2$ ), and  
5 236 ( $V_3$ ). A signal adder 240 is coupled to detectors 214 and 224 to produce a first signal 242 from the signals  $V_1$  and  $V_2$  and a signal subtracting device 250 is coupled to produce a second signal from signals  $V_1$  and  $V_2$ .

[0014] In operation of the device 200, the signal gains  
10  $G_1$ ,  $G_2$ , and  $G_3$  for the three detectors 214, 224, and 234 may be adjusted so that  $V_{1\max} = V_{2\max} = V_{3\max}$  or the differences in the detectors may be electronically calibrated during the processing. The input polarization in the beam 201 may be aligned with the reflection axis of the 3<sup>rd</sup> partial PBS 230.  
15 When this happens, the signal  $V_3$  will be at its maximum and  $V_1$  and  $V_2$  will be equal.

[0015] FIG. 3 shows the variation of  $V_1$ ,  $V_2$ , and  $V_3$  as a function of the input polarization angle when  $V_3$  reaches maximum,  $V_1 = V_2$  so that  $(V_1 - V_2) = 0$ . When the input  
20 polarization angle deviates to the left side of the input polarization that produces the maximum output,  $V_{3\max}$ , in the detector 232, the detector outputs for the detectors 212 and 222 satisfy  $V_1 > V_2$  so that  $(V_1 - V_2) > 0$ . When the input polarization angle is right at the angle for producing  $V_{3\max}$ ,

$V_1 < V_2$  so that  $(V_1 - V_2) < 0$ . Therefore, the quantity  $(V_1 - V_2)$  can be used to indicate both the amount of the deviation and the direction of the deviation of the input polarization with respect to the direction of the 3<sup>rd</sup> partial PBS 230. In particular, this differential signal  $(V_1 - V_2)$  can also tell the direction of the polarization mis-alignment:  $V_1 - V_2 > 0$  indicates that an increase of polarization angle is required while  $V_1 - V_2 < 0$  indicates that a decrease in polarization angle is required.

[0016] Furthermore, when  $V_3 = V_{3\max}$ ,  $V_1 - V_2$  is most sensitive to polarization changes. Therefore using the differential signal of  $(V_1 - V_2)$  as a feedback signal to control the polarization is most sensitive and the feedback loop can produce a high gain.

[0017] In yet another aspect, the sum signal  $(V_1 + V_2)$  is a constant as a function of the polarization angle.

Notably, the sum signal only changes when the optical power changes. Therefore, to eliminate power sensibility in the polarization monitoring in the device 200, the quantity  $(V_1$

$- V_2) / (V_1 + V_2)$  and  $V_3 / (V_1 + V_2)$  may be used. These two values are independent of optical power fluctuations. The signal  $V_3$  (236) from the 3<sup>rd</sup> detector 234 may also be monitored because the signal 252 of  $(V_1 - V_2)$  alone may not indicate the difference between a linear polarization



oriented along the 3<sup>rd</sup> partial PBS 230 and circularly polarized light (RCP and LCP).

[0018] FIG. 4 further shows a polarization control system 400 based on the above polarization monitoring device 200 in FIG. 2. A polarization controller 410 is disposed at the input of the beam 201 to adjustably control the polarization of the input light. The output of the controller 410 is then monitored by the device 200 in an in-line configuration to produce an output beam 202 with a desired output polarization. A feedback control unit 420 is implemented to produce a control signal for controlling the controller 410 based on the signals 242, 252, and 236. This system 400 may be operated to stabilize the output polarization in the output beam 202. This system 400 has the advantages of being highly sensitive to polarization variation, capable of detecting the direction of polarization change, and being insensitive to laser power fluctuation of the input beam.

[0019] Other enhancements and variations of the described implementations may be made.